Numerical simulation on the dependence of carrier transport characteristics on the thickness of the absorbing layer for GaAs-based blocked impurity band (BIB) terahertz detectors

Xiaodong Wang*
The 50th Research Institute of China Electronics Technology Group Corporation
Shanghai, China
wxd06296@163.com

Yulu Chen
The 50th Research Institute of China Electronics Technology Group Corporation
Shanghai, China
yukiylc@163.com

Bingbing Wang
The 50t Research Institute of China Electronics Technology Group Corporation
Shanghai, China
wbb0308201@163.com

Chuansheng Zhang
The 50th Research Institute of China Electronics Technology Group Corporation
Shanghai, China
cszhang519@163.com

Xiaoyao Chen
Laboratory of Advanced Material Fudan University
Shanghai, China
chenxiaoyao@fudan.edu.cn

Haoxing Zhang
The 50th Research Institute of China Electronics Technology Group Corporation
Shanghai, China
13022125120@163.com

***Abstract*—the dependence of carrier transport characteristics on the thickness of the absorbing layer for Gallium Arsenide (GaAs) blocked-impurity-band (BIB) terahertz detector has been investigated in detail. It is found that responsivity linearly increases with the increased thickness of absorbing layer first, and after achieving a peak value, and then starts to dropping slowly.**

Keywords—Numerical simulation, Gallium Arsenide (GaAs), Blocked-impurity-band (BIB), Terahertz detector, Responsivity

I. Introduction

A great many objects with low temperatures in the space can radiate electromagnetic wave with frequency mainly localized in the terahertz (THz)regime. Therefore, these objects cannot be detected by the traditional infrared detection systems or land-based radar systems. However, space-based THz detection systems can supplement the deficiencies of infrared detection systems or land-based radar systems, and thus can largely improve the target detection rate. Recently, the development of space-based THz detection technologies is far beyond our original expectation, and application fields cover space-based remote sensing, atmosphere monitoring [1], and astronomical observation due to the following reasons: (1) the rotation spectrum and oscillation spectrum for the most of material compositions in the space are mainly localized in the THz region; (2) the blackbody radiation peaks for the most of planets, cosmic dusts, and newly born stars are mainly located at the THz region; (3) due to the Doppler effect caused by comic acceleration, the radiations from the distant galaxies have the strongest signals in the THz region [2].

Blocked-impurity-band (BIB) detectors as novel THz detectors can be classified into three types, i.e., Silicon (Si)-based, Germanium (Ge)-based, and Gallium arsenide (GaAs)-based. Among them, Si-based BIB detectors as the most mature BIB detectors have been carried by Spitzer Space Telescope (SST), and James Webb Space Telescope (JWST), and have been actively working for space-based THz detection related application. The key structural characteristics for BIB detectors include an intrinsic blocking layer and a heavily doped absorbing layer, respectively. The incident THz radiations can pass through directly the blocking layer and then be absorbed by the absorbing layer, which can contribute to the electron transitions between the conduction band and the impurity band. Electrons after transitions can be collected by the anode through the bent conduction band, and thus complete the transformation from the optical signal to the electric signal.

GaAs-based BIB detector can response radiation with wavelength larger than 500μm, and thus exhibit attractive potentials in the deeper space and remoter galaxy exploration. However, the recent development of GaAs-based BIB detector is still on the initial stage, and the focal plane arrays (FPAs) of GaAs-based BIB detectors have not been reported yet due to the immature expitaxial techniques of GaAs materials and unstable fabrication techniques of GaAs devices. Besides, some basic physical problems about the functional mechanisms of GaAs-based BIB detectors still need to be solved. Among them, the dependence of carrier transport characteristics on the thickness of the absorbing layer and its physical mechanisms are still unknown. In order to elucidate the above phenomena and the underlying mechanisms, numerical modeling and simulation are performed for GaAs-based BIB detectors in this paper.

II. Structral and Physical Models

Figure 1 shows the structural model of GaAs-based BIB detector. According to Fig. 1, two independent photo-sensitive pixels are individually formed upon the conducting GaAs substrate. From the top to the bottom, one single pixel consists of anode, conducting layer, blocking layer, and absorbing layer, respectively. The cathode as the common electrode is also formed upon the conducting GaAs substrate.

*Corresponding author: Xiaodong Wang

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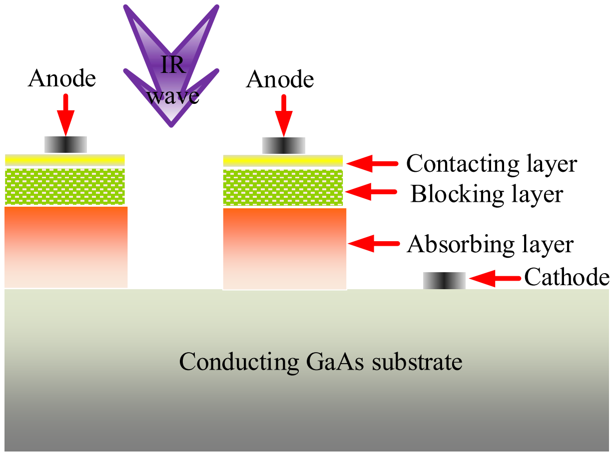

Fig. 1. Structural model of GaAs-based BIB THz detector.

The incident THz wave is front-illuminated on the detector. After passing through the blocking layer, the incident THz wave is absorbed by the absorbing layer, which can give rise to electron conduction and hopping conduction. The conduction path for the former is from the absorbing layer to the anode, and the conduction path for the latter is from the absorbing layer to the cathode.

III. Results and Discussions

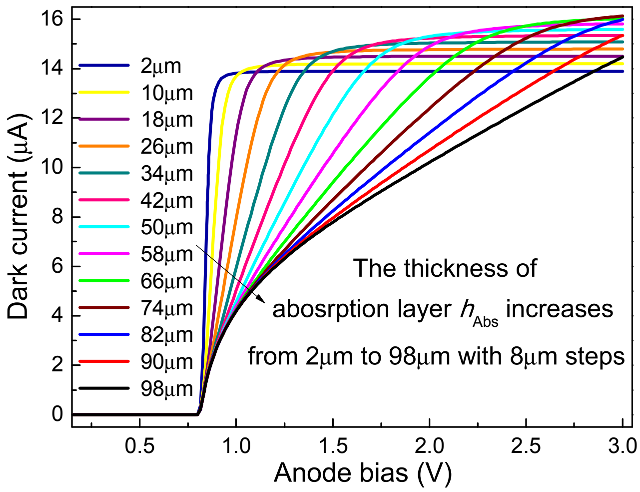

Fig. 2. Dark current versus anode bias with the thickness of the absorbing layer (h_{Abs}) increasing from 2μm to 98μm in 8μm steps.

Figure 2 shows the dark current versus anode bias with the thickness of the absorbing layer (h_{Abs}) increasing from 2μm to 98μm in 8μm steps. One individually inspect the relationship between the dark current and the anode bias, it is found that the fundamental law of dark current with the increased anode bias is the same regardless of h_{Abs}. Specifically, the magnitude of dark current is extremely low when the anode bias is under the certain value, and then the dark current increases rapidly with the increased anode bias, and eventually turn to a saturation value. Besides, as shown by the direction of arrow in Fig. 1, dark current as for a fixed anode bias monotonically decreases with increasing h_{Abs}, which can be attributed to the decline of electric-field-intensity formed by the increased h_{Abs}. Figure 2 shows Light current with 263μm wavelength radiation versus anode bias with the thickness of the absorbing layer (h_{Abs}) increasing from 2μm to 98μm in 8μm steps.

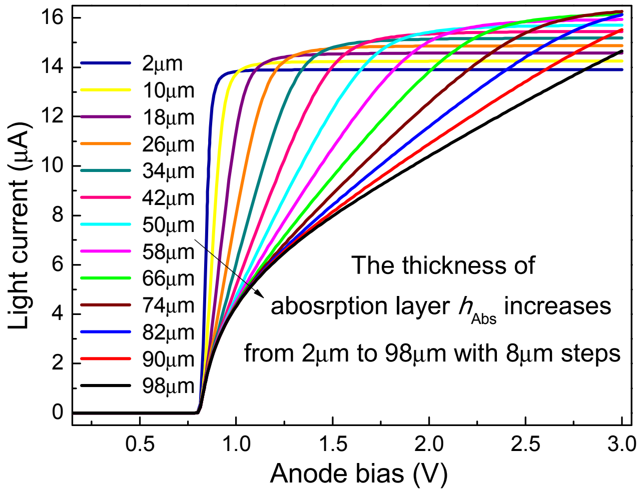

Fig. 3. Light current with 263μm wavelength radiation versus anode bias with the thickness of the absorbing layer (h_{Abs}) increasing from 2μm to 98μm in 8μm steps.

Figure 4 presents the responsivity as a function of h_{Abs} with the anode bias fixed at 1.1V and the incident wavelength fixed at 263μm. It is found that responsivity linearly increases with the increased h_{Abs} first, and after achieving a peak value, and then starts to dropping slowly.

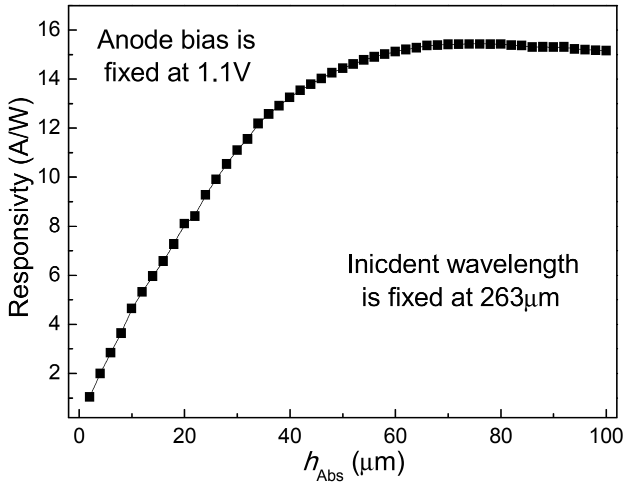

Fig. 4. Responsivity as a function of h_{Abs} with the anode bias fixed at 1.1V and the incident wavelength fixed at 263μm.

IV. Conclusion

In this work, the dependence of carrier transport characteristics on the thickness of the absorbing layer for GaAs-based BIB detector has been investigated in detail.

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